Effect of partial root-zone drying on the growth of potted potato plants under greenhouse conditions

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Abstract

An indoor experiment was conducted at CIP's headquarters in Lima, Peru, to assess the effect of Partial Root-Zone Drying (PRD) irrigation method on the growth and water consumption of potato (*Solanum tuberosum*) plants. Single plants were grown in pots filled with PRO-MIX, a humic soil substrate with a high water retention capacity. The root zone was bisected by a plastic membrane and the root system was equally divided into two mutually impermeable sections. Alternate irrigation was provided to each root zone section, thus PRD treatment plants were frequently watered but an alternate half of the root zone was also frequently induced to experience water deficits. All plants were irrigated on demand, as defined by daily transpiration determined by the weight of the pots. Treatments contrasted conventional irrigation (non-bisected root zone) at four levels of water supply (reposition of 100%, 60%, 45% and 30% of transpired water) with PRD irrigation at three levels of water supply (60%, 45% and 30% of transpired water). Differential irrigation schedules were initiated 28 days after planting and the experiment lasted 90 days from planting. Results showed that tuber dry matter yield decreased as water supply decreased, regardless of the irrigation system. However, yields at the supply level of 60% of transpired water were higher for PRD compared to conventional irrigation. Total biomass followed the same trends as tuber yields. All restricted water supply showed higher water use efficiency (WUE) than the control, regardless of irrigation method. No differences in WUE between the irrigation methods occurred.

Keywords: Potato, Partial Root-Zone Drying, Irrigation.

Introduction

Potato (*Solanum tuberosum*) is a crop that is very sensitive to water stress, which makes it a water-demanding crop, requiring from 400 to 600 liters of water to produce 1 kilogram of tuber dry matter (Beukema and Van der Zaag, 1979). Under field conditions, the water requirements vary between 350 to 500 mm over the growing season, depending on the growing period, environmental conditions, soil type and cultivar (Sood and Singh, 2003) and the crop can respond with increments of up to 2 t/ha for each 2 cm of water lamina (Harris, 1978). The critical period to water deficit in potato is from tuber initiation to maturity (Salter and Goode, 1967; Jensen *et al.*, 2000 and Egúsquiza, 2000) and even short episodes of water stress during this period can cause significant reductions in yield and quality (Miller and Martin, 1987; Kumar *et al.*, 2003). In many rain fed potato-cropping areas of the world, supplemental irrigation is necessary for successful production. However, in many countries water availability for agriculture is being reduced as a consequence of global climate change, environmental pollution and growing demand for other uses. Therefore, great emphasis is being placed on water management for dry conditions based on plant and crop physiology, with the aim of increasing water use efficiency by major crops, which is highly dependent on well-planned watering with low volume and high frequency (Vayda, 1994; Wright and Stark, 1990). The potato's limited tolerance to drought is due to its comparatively shallow root system (50-60 cm) and stomatal closure (Harris, 1992; Kleinkopf and Westermann, 1981; and Bailey, 2000), which is the first physiological response of plants to water deficit, resulting from the regulation of osmotic pressure in the guard cells, mediated by abscisic acid (ABA) released by roots in drying soil. It is known that when the root system is exposed to dry soil, it responds by sending ABA-mediated chemical signals to the leaves to close stomata and reduce the water loss (Davies and Zhang, 1991). Studies on progressive root drying in potatoes have shown that root-sourced ABA reduces stomatal conductance (Liu *et al.*, 2005). This kind of communication is known as non-hydraulic or chemical signaling, which differs from hydraulic signals, which are based on changes in the xylem sap tension (Stikic *et al.*, 2003). Plants with a good watering regime usually keep turgor and their stomata wide open in response to hydraulic signal through xylem water pressure. When the tips of young roots come into contact with dry soil, the release and high concentration of ABA in the xylem prompts stomatal closure to slow down the fall in plant water potential, reduce water loss and bud growth, and prevent wilting (Zhang *et al.*, 1987; Zhang and Outlaw, 2001; Khalil and Grace, 1993; Jia *et al.*, 1996). However, stomatal closure also reduces leaf extension rates (Haverkort and MacKerron, 2000), CO_2 uptake and photosynthetic activity, increases leaf temperature and photorespiration, and is therefore negative for crop production (Egúsquiza, 2000). Manipulating stomatal opening in potato in order to increase the yield per unit volume of transpired water has been suggested (Harris, 1992) although this increment would also mean a reduction in the yield per unit area. Partial root-zone drying (PRD) is an irrigation method that attempts to manipulate plant response to root drying in order to decrease the agricultural demand for water. PRD is an irrigation technique whereby half of the root zone is irrigated while the other half is allowed to dry out. Water supply is then cyclically reversed allowing the previously well-watered side of the root system to dry down while fully irrigating the previously dried side. When PRD irrigation is applied to a crop, the normal root to shoot signaling system that operates in water-deficient soils is altered, causing the drying half of the root system to release ABA thus reducing stomatal aperture, whereas the fully hydrated roots maintain a favorable water status throughout the aboveground parts of the plant. In other words, PRD uncouples the biochemical signal in response to water stress from the hydraulic signal and physical effects of reduced water availability (Bacon, 2003). PRD is based in the theoretical assumption that this mixed root signals causes a limited closure of stomata to restrict water vapor with a minimum effect on CO_2 uptake and photosynthesis (Jones, 1992). It is expected that contradictory root signals brought about by PRD would cause a slight reduction of the stomatal opening that would decrease the water loss substantially with only a small effect on the photosynthesis rate, provided plant turgor is maintained by the watered fraction of the root system. The expected outcome is reasonably good yields with considerable water savings and higher water use efficiency (WUE), which is of paramount importance in areas where water resources are limiting. PRD also stimulates the growth of secondary roots, which reduces the vulnerability to drought (Zhang and Tardieu, 1996). A root system more widely distributed in the soil volume as a result of the lateral dry-wet cycle can result in an improved uptake of nutrients and water by the root system (Kang *et al.*, 1998). PRD has been successfully used in fruit-producing crops such as tomatoes, grapes, oranges, olive trees, tomato, corn, cotton and others, but no extensive research has been conducted in root and tuber crops, particularly in semi-arid environments where the water resource is scarce. The results in the former crops demonstrated that PRD has no major negative effect on the yield but improves fruit quality with a reduction of more than 50% of the consumption of water (Loveys *et al.*, 2001). However, important issues such as the growth stage at which PRD should be applied to the potato crop to improve WUE without yield reductions remain to be addressed (Liu *et al*, 2006a,b). Interestingly, Xu *et al.*, (1998) stated that ABA stimulates tuber formation in potato whereas Jackson (1999) has suggested that ABA participates in the control of tuber formation although its direct effect is not totally clear yet. The effect of partial root drying in tuber formation has not yet been elucidated.

An indoor experiment was conducted at CIP's headquarters in Lima, Peru, to assess the effect of PRD irrigation method on the growth and water consumption of potato plants. The objective of this study was to test the effects of PRD on WUE and tuber production as compared to full irrigation, and investigate its effect on morphological and physiological characteristics of the potato crop.

Materials and methods

Single plants of the potato variety Unica were grown in pots filled with 1.2 kg of PRO-MIX, a humic soil substrate with a high water retention capacity. The root zone in each of the pots selected for the PRD treatments was bisected by a plastic membrane and the root system was equally divided into two mutually impermeable sections. Each side of the root zone was identified. After emergence the pots were covered with a plastic film all around the plants to prevent evaporation from the soil. Treatments contrasted conventional irrigation (non-bisected root zone) at four levels of water supply (reposition of 100%, 60%, 45% and 30% of transpired water) with PRD irrigation at three levels of water supply (60%, 45% and 30% of transpired water). All plants were irrigated on demand, as defined by daily transpiration determined by the weight of the pots. In the PRD treatments, alternate irrigation was provided to each root zone section, thus PRD treatment plants were frequently watered but an alternate half of the root zone was also frequently induced to experience water deficits. The sequence of alternating watering was determined by the accumulated daily transpiration, being the threshold an accumulated transpiration of 900 g. When this level of accumulated transpiration was reached, watering was switched to the other side of the divided pot. Up to days 27 after planting, all pots were continuously watered to soil capacity. Differential irrigation schedules were initiated 28 days after planting and the experiment lasted 90 days from planting.

Results and discussion

The average total amount of water applied to plants in each treatment is shown in Figure 1. This amount is the sum of the non-differential full watering common to all plants during the first 27 days of the experiment plus the amount of water applied during the experimental phase of differential irrigation from day 28 to the end of the trial. Although plants were irrigated on demand as determined by the rate of daily transpiration, no differences in water consumption between the treatments with similar preset percentages of water reposition relative to daily transpiration were observed. This was due to the fact that rates of transpiration of corresponding normal and PRD treatments with similar preset percentages of water reposition were equivalent, as shown in Figure 2. As a consequence of this lack of effect of irrigation method on daily transpiration and water consumption, total biomass produced under either conventional and PRD irrigation did not show differences at the same level of water restriction, except for the 60% level at which total biomass produced under PRD were higher than the yield under the conventional watering procedure (Figure 3). Overall, total biomass production was a function of water consumption. Figure 3 shows that the control plants produced the higher biomass yield and that significant reductions in total biomass were gradually caused by the reductions in water supply, regardless of the irrigation method.

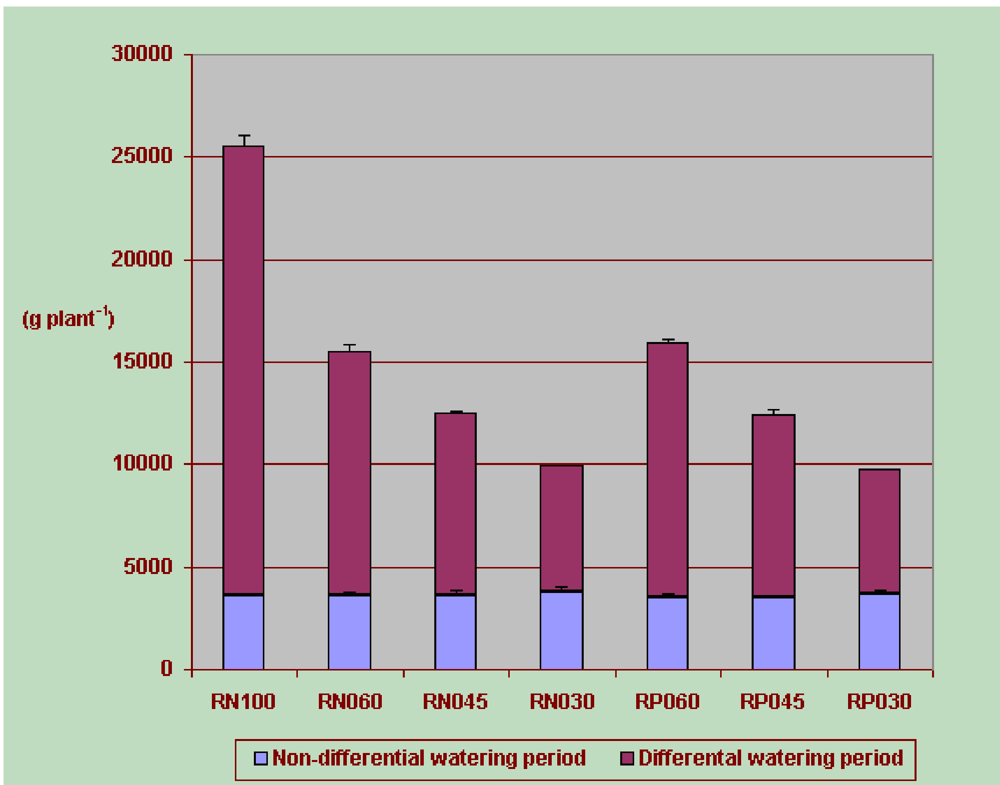

Figure 1. Total applied water

Tuber production followed exactly the same trend described for total biomass, as can be seen in Figure 3. As to harvest index, a significant reduction was observed at the lowest level of water consumption in both the conventional and PRD irrigation methods, as shown in Fig. 4.

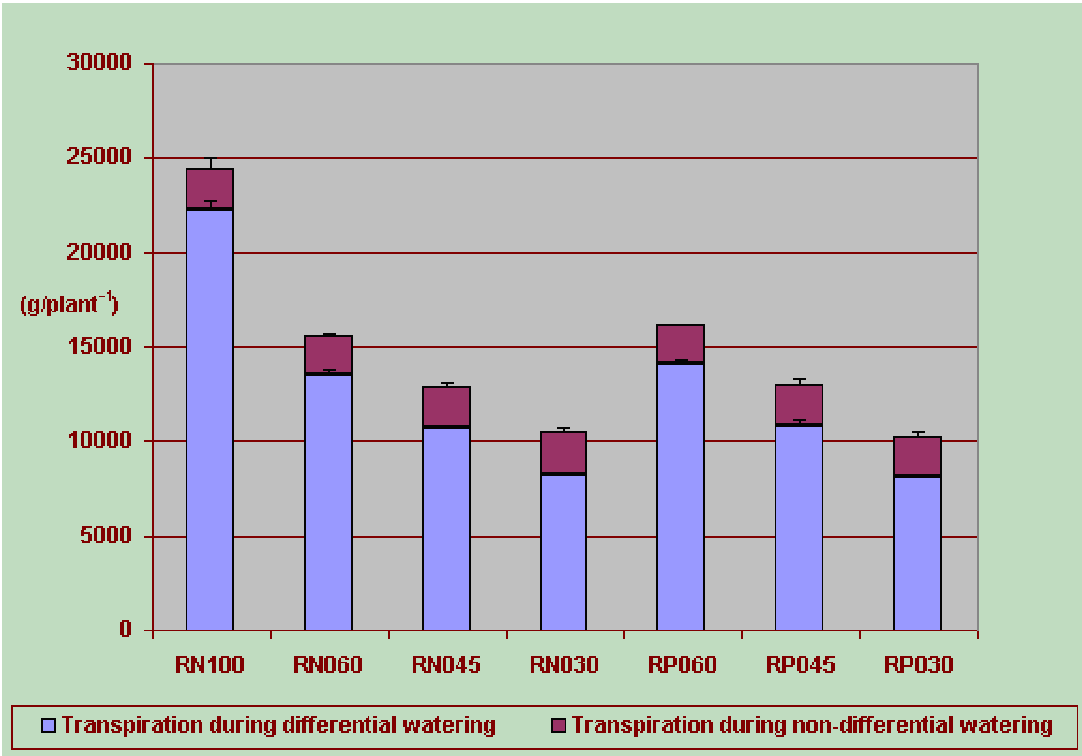

Figure 2. Total Transpiration

As to water transpiration efficiency (WTE), which is the ratio of carbon fixation to water loss (in our case was measured as the ratio of biomass production to water loss), it was calculated for both total transpiration (water transpired during the full growing period, from plant emergence to harvest) and for the period of differential irrigation (from day 27 onwards), as shown in Figure 5. It is not surprising that WTE was significantly higher during the period of differential watering, as that resulted from the shorter period of transpiration included in the analysis. However, it is noteworthy that in all cases water restriction increased WTE compared with the control at both the total growing period and during the period of differential irrigation. Moreover, the level of water restriction, regardless of the irrigation method, positively increased the gap between total WTE and the efficiency during the period of restricted irrigation. Similar results were obtained for water use efficiency, as shown in Figure 6, due to the experimental coupling between water application and transpiration, as the latter defined the demand. It is likely that differential water application based on field capacity rather than transpiration would bring about different results, as it will allow a more clear cycle of watering and drying of the halves of the root zone. It is also likely that the watering determined by daily transpiration has not allowed a long and intense enough partial drying of the root zone, which could explain the absence of differences between the two restricted watering systems applied in this experiment.

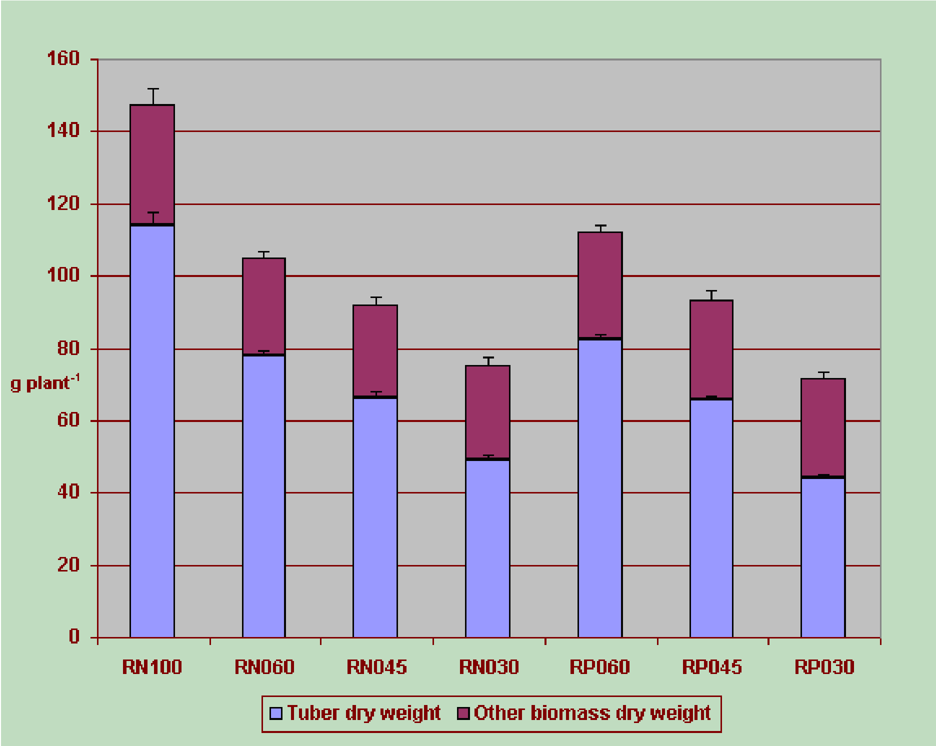

Figure 3. Total Dry Biomass

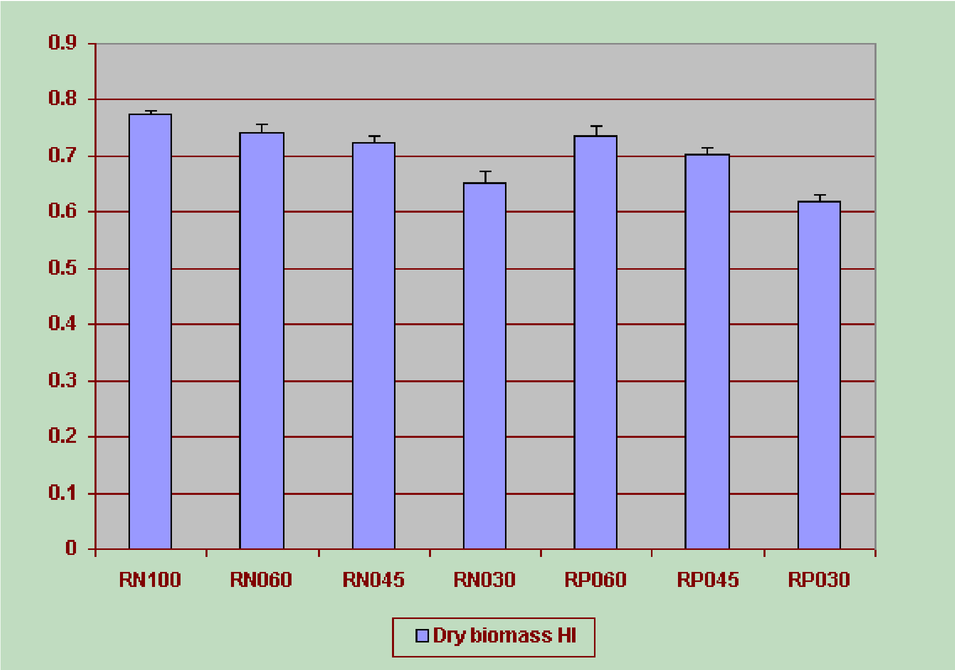

Figure 4. Harvest Index

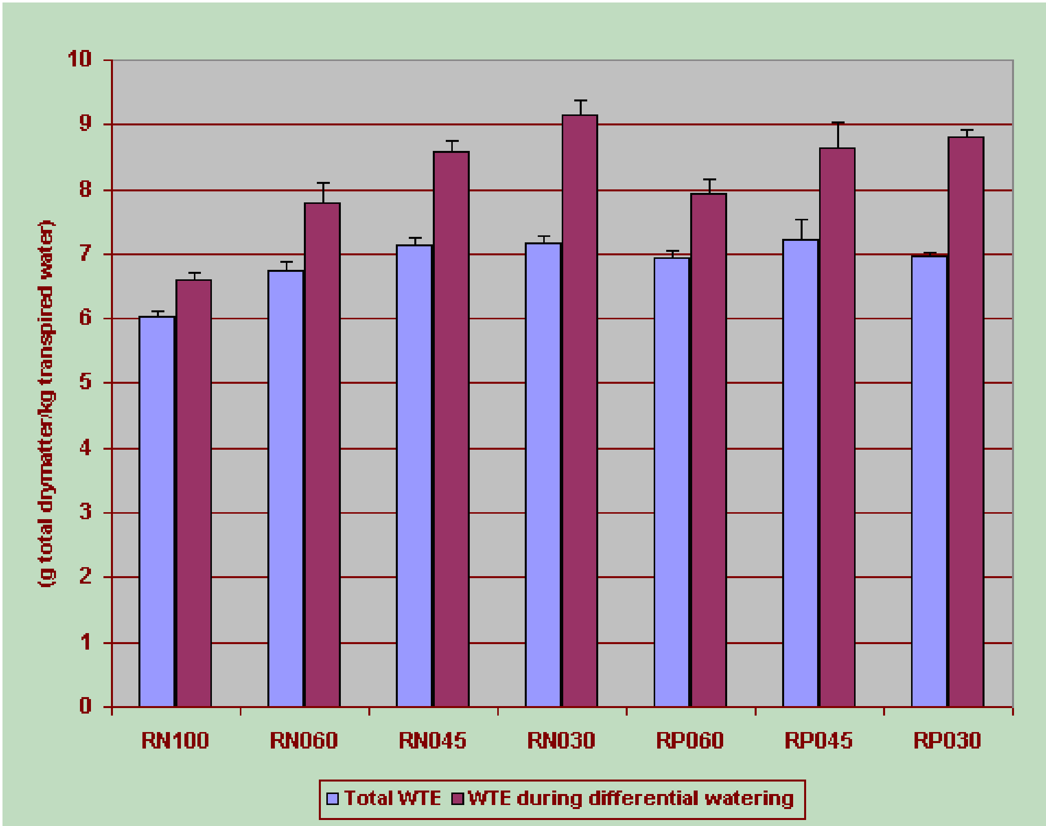

Figure. 5. Water Transpiration Efficiency

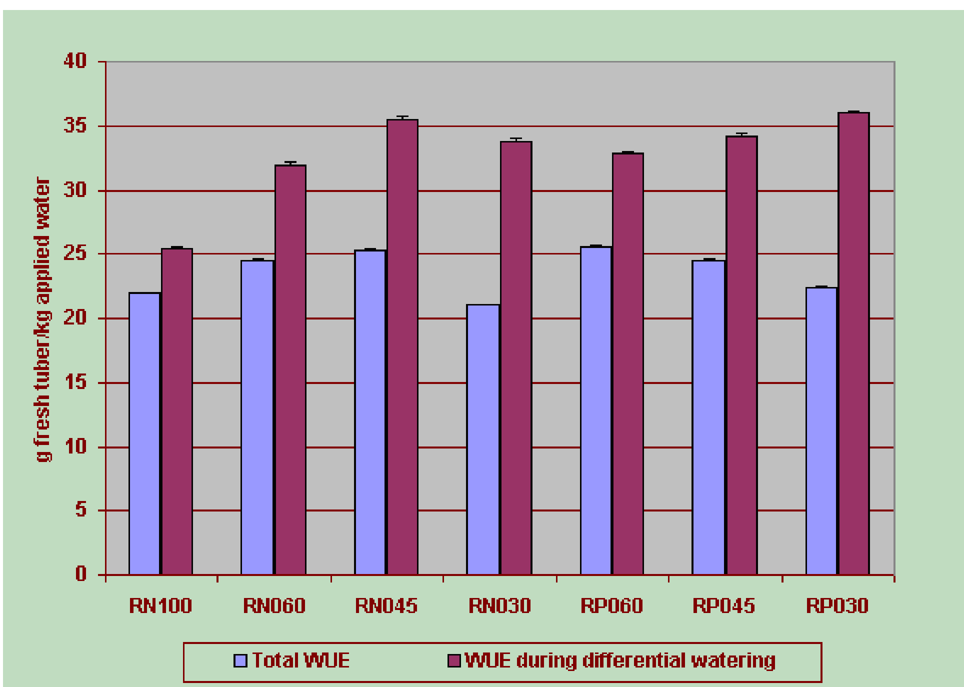

Figure 6. Water use efficiency

Conclusions

It was evident that water restriction, regardless of irrigation method, increased both WTE and WUE. However, the trade off between the reduction of both water use and tuber production has to be taken into consideration for practical applications of restricted irrigation. Further work will explore the responses to PRD in the field.

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